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(54) Title: ULTRASONIC ELECTRO-ACOUSTIC TRANSDUCERS

(57) Abstract

An ultrasonic electro-acoustic transducer (50) comprises an electro-acoustic element (53) having an elongate working face, bearing a first electrode structure (70), and a second face spaced from the said working face and bearing a second electrode structure (71). Electrical driving circuitry is connected to the first and second electrode structures for applying electrical driving signals therebetween to cause the element to vibrate so that ultrasonic acoustic waves are propagated, into a medium coupled to the said elongate working face, in a direction away from that working face. The said electro-acoustic element, electrode structures and driving circuitry are such that the effects of the said electrical driving signals differ at different locations along the said working face so as to counteract destructive interference effects that would otherwise occur at points, in the said medium, along a target line parallel to the said longitudinal axis and spaced at a predetermined distance in the said direction from the said working face.
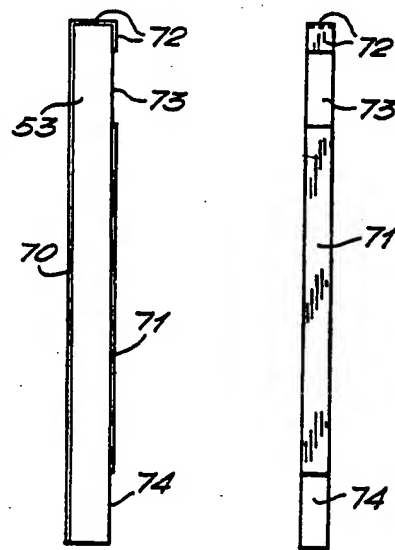
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It is not yet known for which States of the former Soviet Union any designation of the Soviet Union has effect.

ULTRASONIC ELECTRO-ACOUSTIC TRANSDUCERS

The present invention relates to ultrasonic
transducers for use, for example, in detecting the
presence of an object in a predetermined region without
5   contacting the object.

Many methods have been proposed for detecting the
presence of an object within a predetermined area without
contacting the object concerned. These methods include
radar, sonar, light curtains and other optical
10   techniques. In a sonar arrangement, for example,
acoustic waves are emitted from a transmitter device in
the direction of the object, and a receiver device,
generally located adjacent to the transmitter device, is
used to detect waves reflected back from the object
15   concerned, and to provide an electrical output signal in
response to those reflected waves. By analyzing the
output signal it is possible to determine whether or not
an object is present within the monitored area of the
arrangement.

20   In the majority of applications in which acoustic
waves are employed to detect the position of an object
the dimensions of the transmitter and receiver devices
are negligible compared to the range (measured from the
devices) of the object to be detected. However, in
25   certain applications it may necessary to position the
transmitter and receiver devices relatively near to the
object to be detected, so that the dimensions of the
devices are no longer negligible in comparison with the
object range.

30   One such application involves the use of ultrasonic
acoustic waves to detect the presence of threads in
textile machinery. In such machinery the space available
for mounting the transmitter and receiver devices is
limited, and the relatively low ultrasonic wavelengths
35   (for example 0.33mm) must be used to detect the threads
(having diameters as small as 0.1 mm) satisfactorily. In
such circumstances the returned acoustic waves are weak,

so that operation over long ranges is not generally possible.

In such use of ultrasound to detect threads an additional problem arises in that the position of the

5   thread (as it is supported in the machinery) may vary laterally by distances that are large compared to the diameter of the thread itself. Such variation is practically inevitable and it is accordingly required to be able to detect the position of the thread reliably

10   over a predetermined region that is large compared to the thread diameter.

In an attempt to satisfy this requirement an elongate ultrasonic transducer could be disposed with its longitudinal axis perpendicular to the axis of the thread

15   to be detected. Such a disposition can in principle permit lateral variation of the thread position to be accommodated.

However, with such an elongate transducer arrangement it is found that the range of lateral

20   positions over which the thread can be detected reliably may be much less than the length of the elongate transducer, for reasons that will be explained in detail hereinafter with reference to Figure 9.

It would in principle be possible to simply increase

25   the length of the transducer to increase the range of positions in which the thread can be detected, but such a transducer of increased size would be more costly, and in certain applications space is not available to mount such a large transducer. In addition, if the length is

30   increased it is found that the received signal amplitude may become too weak for reliable detection because the generated acoustic energy is distributed over a wider area.

It is desirable to provide an ultrasonic transducer

35   device in which the above-mentioned range can be increased without increasing the device dimensions unacceptably.

According to the present invention there is provided
an ultrasonic electro-acoustic transducer comprising an
electro-acoustic element having an elongate working face,
bearing a first electrode structure, and a second face
5   spaced from the said working face and bearing a second
electrode structure;

there being electrical driving circuitry
connected to the first and second electrode structures
for applying electrical driving signals therebetween to
10   cause the element to vibrate so that ultrasonic acoustic
waves are propagated, into a medium coupled to the said
elongate working face, in a direction away from that
working face;

and the said electro-acoustic element,
15   electrode structures and driving circuitry being such
that the effects of the said electrical driving signals
differ at different locations along the said working face
so as to counteract destructive interference effects that
would otherwise occur at points, in the said medium,
20   along a target line parallel to the said longitudinal
axis and spaced at a predetermined distance in the said
direction from the said working face.

In a method of detecting a filamentary body,
supported so that it extends longitudinally across a
25   predetermined position, ultrasonic acoustic waves are
transmitted towards the said predetermined position,
transversely with respect to the longitudinal axis of the
said filamentary body, and such waves diverted back by
the filamentary body, from the said predetermined
30   position, are monitored. Preferably, in such a method a
transducer as set out above may be used to transmit and
detect such acoustic waves.

Apparatus may be provided which includes means for
supporting a filamentary body so that it extends
35   longitudinally across a predetermined position, relative
to a support portion of the apparatus, and monitoring
means including ultrasonic transducer means, preferably

constituted by a transducer as set out above, mounted on
the said support portion and operable to transmit
ultrasonic acoustic waves towards the said predetermined
position, transversely with respect to the longitudinal
axis of such a body so supported, and to detect such
waves directed back, by such a body, from that position.
waves directed back, by such a body, from that position.

For a better understanding of the invention, and to
show how the same may be carried into effect, reference
will now be made, by way of example, to the accompanying
drawings, in which:-

Figure 1 shows a schematic perspective view of a
draw frame of a textile machine;

Figure 2 shows a schematic perspective view of a
draw frame, of a textile machine, including apparatus in
which a device embodying the present invention is
incorporated;

Figure 3 shows a schematic plan view of a component
of the Figure 2 apparatus;

Figure 4 shows a block diagram of electronic
circuitry employed with the apparatus of Figure 2;

Fig. 5 shows a diagrammatic side view of an
ultrasonic transducer device embodying the present
invention;

Fig. 6 shows a more detailed longitudinal sectional
view of the device of Fig. 5;

Fig. 7 shows a sectional view of the Fig. 6 device,
as seen along a line VII-VII in Fig. 6.

Figs. 8(A) and 8(B) show respective side and rear
elevational views of parts of the transducer device of
Figs. 6 and 7;

Fig. 9 shows a schematic perspective view of a
thread detector arrangement including an elongate
ultrasonic transducer not in accordance with the present
invention;

Fig. 10 is a graph illustrating the amplitude of
acoustic waves produced by the transducer of Fig. 9 as a

function of position along the length of the transducer;

Fig. 11 is a graph corresponding to Fig. 10, but
illustrating characteristics of the device of Figs. 6 and
7; and

5   Figs. 12 to 15 show diagrammatic representations of
alternative forms of the parts of Figs. 8(A) and 8(B).

Figure 16 is a polar plot showing amplitude
variation of acoustic waves produced by the device of
Figs. 6 to 8;

10   Figure 17 shows a diagrammatic view illustrating
transmission and reflection of acoustic waves to and from
the device of Figs. 6 to 8; and

Figures 18 and 19 show respective diagrammatic views
corresponding to Fig. 17, for use in illustrating effects
15   of variation in dimension of the transducer device.

The main structure of the draw frame of Figure 2
corresponds to that of Fig. 1, but Fig. 2 shows the
aforementioned pigtail 5a and balloon ring 5b. The draw
frame of Fig. 2, however, is provided with a support
20   member in the form of a mounting bar 2 which extends
along the complete length of the textile machine, between
each outcoming thread 3 and the main body of the machine.
A sensor unit 1 is mounted, on the bar 2, so as to be
operative in a horizontal plane which is parallel to the
25   mounting bar 2 and intersects the thread 3 at a position
between nip point 4 (between rollers 204) and the pigtail
5a. At such a position, angular and lateral movement of
the thread is within acceptable limits and there is
sufficient space for mounting the sensor unit 1.

30   An elongate ultrasonic transducer device 6 is
mounted in the sensor unit 1 so that the longitudinal
axis of that device 6 lies in the said horizontal plane,
at an angle of approximately 45° to the axis of the
mounting bar 2. It will be appreciated that, over a
35   complete textile machine, individual sensors will be
spaced apart from one another according to the spacing of
threads on the machine.

In Figure 3 the sensor unit 1 can be seen in more
detail. It is preferably attached to the bar 2 by means
of a plug attachment 8, and has an indicator light 7
which is preferably an LED.

5   The position and angle of the thread 3 is likely to
vary. It is thus not appropriate to focus the beam of
ultrasound emitted from the transducer device 6.
Instead, the transducer device 6 is designed to ensure
that there are no 'dead spots' within a predetermined
10   region in which the thread is expected to be found.

It is arranged that the thread 3 will be between
27.5 and 42 mm away from the sensor unit 1 and will have
a lateral movement of ± 6 mm in the horizontal plane.
The angular displacement from the vertical is expected to
15   be ± 10°. This movement creates a notional rectangle (in
the horizontal plane) in which the thread is expected to
be found, with its nearest edge parallel to the
longitudinal axis of the transducer device 6. This edge
is 27.5 mm away from the transducer device 6 and is 12 mm
20   long. The rectangle has a length of 14.5 mm. In three
dimensions, the volume in which the thread 3 is expected
to be found is a notional parallelepiped whose dimensions
are the same as for the rectangle above, but where depth
is defined by the depth of the field of view of the
25   transducer device 6.

Figure 4 shows a block diagram of electronic
circuitry involved in the detection of the thread by the
sensor unit 1.

This circuitry is divided between a control board 9,
30   which controls 16 such sensor units and a sensor board 10
located within the sensor unit 1.

The operating frequency is chosen to satisfy the
requirements that i) the sound is not heavily attenuated
by air as it travels though the greatest distance (85
35   mm), and ii) the wavelength is comparable to the diameter
of fine threads (0.1 mm).

Further, since a single transducer is to be used as

both the transmitter and receiver for the pulse-echo
technique, then there should be a sufficient number of
cycles between transmission and reception for the
transmission oscillation to decay. This will depend on
5   the operating frequency, f, the damping characteristics,
Q, and the magnitude of the received signal. For a
closest approach of 27.5 mm, the decay time must be 150
µs or less.

Bearing in mind the variation of the received signal
10   with thread diameter, the wavelength (and frequency) of
operation are chosen to achieve a situation in which the
reduction in reflection with reducing thread diameter is
balanced by increase in reflection, or backscatter,
produced by interference effects, thereby obtaining an
15   overall reflection coefficient which is largely
independent of thread size. The selected operating
frequency is 1.0 MHz. This has a wavelength in air of
0.33 mm, comparable to normal thread diameters. At this
frequency, there are 150 cycles between transmission and
20   reflection, enough to allow the use of a single
transducer in the pulse-echo technique. At this
frequency, the reflected signal is largely independent of
thread diameter.

A microprocessor 11 activates the sensor board 10
25   via a driver 12. This has the effect of driving an
oscillator 13 which generates a signal which is tuned to
the frequency of the transducer 6 (approximately 1MHz).
This signal is amplified by a driver 14 and applied to
the transducer 6 as a burst of 30 half-cycles of
30   amplitude +38V.

The transducer is thereby caused to emit a burst of
acoustic waves which are reflected by the thread 3 (Fig.
3). The reflected signal is received by the transducer 6
which is thereby caused to generate an electrical signal.
35   This detected signal is amplified by a factor of 3500 by
a band-pass amplifier 15 which has a Q of 5.

This thread sensing system is designed to

distinguish the reflection from a thread - a wavetrain or
burst of 30 pulses at 1 MHz - from a sharp electrical
spike such as electrical noise produced by a switched
mode power supply used to power a drive motor on the
5   textile machine.

The filtered output of amplifier 15 is sent via a
line driver 16 to a detector 17. The detector 17 detects
whether the signal exceeds a predetermined threshold a
given number of times in a given number of consecutive 1
10   μs periods.

Because the amplifier 15 has a relatively wide band
pass, an electrical spike will retain its sharp form and
thus will cross the threshold only once or twice during a
time interval in which the thread reflection will cross
15   the threshold at least ten times. This allows the
reflected signals to be distinguished clearly from such
electrical noise.

The signal from the detector 17 is sent to the
microprocessor 11 for further analysis.

20   The thread detection system must sense the small
reflected signal from a thread, but should not sense
various other signals from textile machinery and
electrical interference, to minimise the chance of such
noise giving a false detection result. In operation,
25   there are both minimum and maximum distances at which the
thread 3 can be positioned away from the transducer
device 6. Because of the finite speed of sound, this
means that there is a range of time, after pulse
transmission, outside which no valid reflection can be
30   received. If the circuit is rendered non-sensitive
outside this time span, there is no possibility of noise,
false reflections, etc, giving erroneous results then.

Accordingly, the reflected signal is time gated by
the microprocessor 11 so that only reflections from
35   objects 27.5 to 42.5 mm away are taken into account.

The microprocessor 11 may also introduce a delay
before the circuit indicates that a thread is not

present, to allow the thread to be removed by an operator
for a short time, e.g. for inspection of the thread,
without triggering the system that takes corrective
action for a broken thread.

5   In the illustrated embodiment, the detection system
looks for the thread (3) 125 times in a second. If it
does not 'see' the thread for 2 seconds then it decides
that the thread 3 is broken. The microprocessor 11 sends
a message to a "host" system, i.e. a further control

10   system (not shown) that takes corrective action such as
causing a solenoid to operate a brake on the 'roving',
and activates the indicator light 7. Once the thread 3
has been mended, the sensor must 'see' it at least four
times in a three-second period to decide that the thread

15   has indeed been mended. It then sends an appropriate
message to the "host" system and switches off the
indicator light 7.

        Such a decision system can ensure a low-error
operation, and permits the yarn to be rethreaded without

20   confusing the corrective control system. The detection
system is sensitive to signals of 70μV. This is achieved
by careful noise-reduction and filtering.

        The cases of the sensor unit 1 and transducer 6, and
a front electrode of that transducer are all connected to

25   a zero-potential pin (not shown). This provides a
complete earth shield and so insulates the detecting
system from capacitively coupled noise sources.

        The transducer device 50 of Fig. 5 includes a case
51, a backing layer 52, an active piezo-electric element

30   53 in contact with the backing layer 52, and an acoustic
matching layer 54 in contact with a working face of the
piezo-electric ceramic element 53. Respective connecting
wires 55 are used to convey electrical signals to
respective electrodes (not shown) on the said working

35   face and an opposite face of the element 53.

        In use of the device 50, the piezo-electric active
element 53 serves to convert electrical oscillations into

mechanical vibrations and vice versa. The element 53 generally has its dimensions and constituent material chosen such that it resonates at the frequency of the acoustic waves be produced.

The matching layer 54 is provided to facilitate effective transfer of energy between the working face of the active element 53 and an external gaseous propagating medium. In practice it is found that because the acoustic impedances of practical piezo-electric materials are several orders of magnitude greater than those of propagating media of interest (for example, air) energy transfer between the element 53 and the medium is very low unless a suitable matching layer 54 is present. According to conventional acoustic theory, when a matching layer is interposed between two media the transfer of energy between the two media is greatest when the thickness of the matching layer is equal to one quarter of the wavelength of acoustic waves in the layer and when the acoustic impedance of the material of the matching layer, at that wavelength, is equal to the geometric mean of the respective acoustic impedances of the two media.

The backing layer 52 serves to damp vibrations of the active element 53.

The transducer device of Fig. 5 may be used in a "pulse-echo" system in which, in a first (transmitting) operating mode, a burst of electrical driving signals of a predetermined ultrasonic frequency is applied to the piezo-electric element 53 via its electrodes so as to cause the upper (working) face of that element (which is in contact with the matching layer 54) to vibrate at the said ultrasonic frequency, thereby causing acoustic waves to be propagated from the free face of the layer 54 into the adjacent air. In a second (receiving) operating mode, commencing a predetermined time interval after termination of the said first burst of driving signals, the device 50 is used as a receiver of acoustic waves,

the incidence of such waves upon the free face of the
matching layer 54 causing vibration of the piezo-electric
element 53, whereby electrical signals in accordance with
the received acoustic waves are produced in the

5   connecting wires 55.   By analysis of these electrical
signals it is possible to determine whether or not an
object is present at a target position a predetermined
distance from the said working face.

        In certain applications, such as detecting the
10   presence of a thread in textile machinery, spatial
restrictions make it necessary to arrange the transducer
device very close to the object to be detected.   In such
a case, however, a problem arises in that the above-
mentioned predetermined time interval, between the end of

15   the transmitting mode and the start of the receiving
mode, must be very short, because of the short time taken
for acoustic waves to travel from the transducer to the
object to be detected and back.   Previously-considered
transducer devices have not been capable of operating

20   satisfactorily in such a pulse-echo system, because the
time taken for oscillations to die away sufficiently for
effective detection of received ultrasonic signals to be
carried out is too great.

        The device 50 of Fig. 5 may be regarded as a
25   resonant oscillator whose sharpness in resonance may be
described by its quality factor Q.   The damping
characteristics of any oscillator are characterised by
its Q factor, which is the reciprocal of the fraction of
the oscillator's energy lost in each cycle of

30   oscillation.

        A high Q is associated with a sharp resonance and
consequently a high operating efficiency in converting
electrical oscillations into acoustic waves and vice
versa.   A high Q is also, however, associated with a long

35   decay time for residual oscillations following the
removal of electrical drive signals.   The number of
cycles N required for oscillations to decay in amplitude

by a factor A may be expressed by the equation:

$$N = \frac{Q \ln A}{\pi}$$

Since at any given frequency the duration (period) T
of each cycle is fixed, it follows that the time taken
for oscillations to decay in amplitude by the factor A is
given by:

$$t_{decay} = N T = \frac{Q T \ln A}{\pi} \qquad \ldots\ldots(1)$$

Thus, in short-range detecting applications, a
difficulty arises in that although a high Q is desirable
from the point of view of maximising operating
efficiency, the higher the value of Q the higher the
minimum separation of the object to be detected from the
transducer device must be. For practical reasons, it is
not always possible to simply increase that minimum
separation, for example because space is not available or
because the attenuation over the longer distances
involved is too great for reliable detection of reflected
ultrasonic waves.

The particular factors influencing the settling time
will now be discussed in more detail.

The transducer device 50 of Fig. 5 consists of two
resonant components, namely the piezo-electric element 53
and the matching layer 54, and two non-resonant
components, namely the case 51 and the backing layer 52.

The case 51 does not perform any positive functions
as an oscillator and should therefore be designed to
oscillate as little as possible, and to isolate the
device acoustically from a support member (such as a
circuit board) on which the device is mounted. The case
51 may also function as a continuation of the backing
layer 52.

The remaining components of the device 50 may be
regarded as a set of acoustically-coupled oscillators,
each of which oscillators has its own resonant frequency

and damping characteristic. In the latter respect, each component is capable of storing energy and ringing (dissipating residual stored energy) even after electrical drive signals to the device have been removed.

5   In addition, since the components are in contact with one another, energy of oscillations will transfer between the different components, depending on their individual properties.

When electrical drive signals are removed from such

10   a set of coupled oscillators, residual energy is dissipated by a combination of energy loss in each individual oscillator, and by the transfer of energy from oscillators of naturally high Q to those with a lower Q. Thus, the particular overall Q value of a system of

15   oscillators, i.e. the overall transducer device, is dependent upon the internal absorption of energy of the individual oscillators and upon the transfer of energy between them

In a particular transducer device 50 for operation

20   with air as the propagating medium it is found that the factor which dominates the overall damping time of the transducer is the damping time of the matching layer 54. This is because the layer 54 is preferably made of a silicone rubber of low density, silicone rubber being an

25   optimal material for the matching layer because of its low acoustic impedance.

As mentioned above, the matching layer 54 should conventionally have an acoustic impedance which is equal to the geometric mean of the respective acoustic

30   impedance of the element 53 and the propagating medium, in this case air. Since typical piezo-electric materials have an acoustic impedance of approximately 3×10^7 Rayls $(kgm^{-2}s^{-1}$ and air has an acoustic impedance of only 400 Rayls, the impedance of the matching layer 54 should

35   conventionally be around 1.1×10^5 Rayls. However, no continuous homogenous solid having such a low acoustic impedance is known. The solid material with the lowest

known acoustic impedance is a low density silicon rubber, which at the generally preferred density of around 1.05×10^3 kgm^{-3} has an impedance of approximately 10^6 Rayls. Various transducer devices are available which employ a matching layer of such a silicone rubber. However, such devices are not suitable for operation over short ranges when the same device must be used both to transmit and receive ultrasonic acoustic waves. This is because the silicone rubber has a naturally high Q (low absorption), so that residual energy stored in the matching layer cannot be dissipated quickly enough for received ultrasonic waves, reflected back from an object to be detected, to be distinguished reliably from ringing effects.

In order to reduce the overall effective quality factor of the device 50 it is desirable to modify the effective quality factor of the dominating oscillator, in this case the rubber matching layer 54. Preferably also the respective quality factors of each of the component oscillators will not be unduly different in value from that overall effective quality factor.

Energy may be dissipated from the matching layer in three ways: dissipation into the air; transfer of energy into the piezo-electric element; and internal absorption. In practice, the most important dissipation process is that of energy transfer into the piezo-electric ceramic element. Considering this process in more detail, the quality factor Q_{rubber} of the rubber material may be expressed as

$$Q_{rubber} = \frac{-\pi}{2 \ln (R\alpha)} \qquad \ldots\ldots(2)$$

where R is the reflection coefficient at the piezo-rubber interface, and

$1/\alpha$ is the factor by which the amplitude of acoustic waves passing through the rubber is attenuated in a distance of one half of a wavelength.

From the above expression, it is apparent that
Q_{rubber} may be reduced either by increasing the internal
damping and thus lowering α, or by decreasing the
reflection coefficient R.

5   The internal damping of the rubber may be increased
by loading the silicone rubber material with a powder-
form material such as fine glass powder, fly ash, plastic
or metal powder.

The reflection coefficient R may be reduced by
10   appropriately modifying the silicone rubber so that its
acoustic impedance approaches that of the piezo-electric
element. The acoustic impedance of a material is given
by the product of the material density and the speed of
propagation of acoustic waves (at the frequency of
15   interest) through the material. Accordingly, since the
piezo-ceramic material has an acoustic impedance that is
an order of magnitude greater than that of the rubber,
one approach to reducing the reflection co-efficient at
the ceramic/rubber interface is to increase the density
20   of the rubber material. As the density of the rubber
increases the reflection of acoustic waves at the
rubber/ceramic interface is reduced, so that during
ringing more energy can escape from the rubber layer 5 to
the piezo-electric element 53 which is damped by the
25   backing layer 52. Using this approach it is possible to
optimise the transducer for sensitivity and short
operating range.

As mentioned above, heretofore it has been the
practice to employ as the material of the matching layer
30   a silicone rubber of a density around 1×10^3 kgm^{-3} (for
example silicone rubber of the proprietary coding GE
RTV615 manufactured by General Electric). In such a
case, since the speed of propagation of ultrasonic waves
through rubber material is 1000 ms^{-1}, the acoustic
35   impedance of the rubber is around 10^6 Rayls. In a device
embodying to the present invention, however, the density
of the rubber is increased to between 1.1 and 2.1 x

$10^3 kgm^{-3}$, so that the acoustic impedance is increased proportionately to between 1.1 and 2.1×10^6 Rayls. Accordingly, the reflection coefficient is reduced, lowering the effective quality factor Q_{rubber} of the

5   rubber, so that the overall quality factor of the transducer is also reduced. Such a reduced overall Q can provide a value settling time that is sufficiently low to permit the transducer to operate reliably to detect objects placed at a distance of 12 mm or less from the

10   device.

It will be appreciated that by further modifying the properties of the rubber matching layer it may be possible to provide a transducer capable of operating at even shorter ranges, such as 8 mm or less. In such a

15   case, it may be necessary to employ a combination of material loading (to increase the internal damping) and increased rubber density to achieve the desired settling time.

By careful control of the material properties and

20   design of the above-mentioned components of the transducer device, the applicants have found that it is possible to control the overall Q value of the transducer such that efficient operation is possible with a desirably short settling time. In this respect, it will

25   be appreciated that when a device embodying the present invention is employed in a short-range detecting application, by virtue of its reduced settling time the minimum separation of the device from an object to be detected can be correspondingly reduced, so that the

30   disadvantage conventionally associated with a reduced Q value, namely loss in operating range, does not represent a practical difficulty.

A specific example of a device embodying the present invention will now be described in more detail with

35   reference to Figs. 6 and 7. In this example, the transducer device is required to operate reliably over a minimum range of 27.5mm. The frequency of operation is

chosen to be 1 MHz so as to provide a wavelength in air
of acoustic waves of 0.33mm, sufficiently small to
facilitate detection of threads of diameter as low as
0.1mm.

5   The time taken for acoustic waves to travel to and
from an object at this minimum range is approximately 150
μs. This corresponds to 150 cycles of oscillations at 1
MHz. Assuming that the amplitude of oscillations of the
transducer is required to decay by a factor A of 5×10^5
10   (114 dB) in this number of cycles, it follows from
equation (1) above that Q must be less than 36.

          The device of the present example is designed to
have an overall Q factor close to 30. Such a value
affords acceptable efficiency in transmission and
15   reception, but is small compared to the natural Q value
of silicone rubber (of the order of 150 at the
frequencies of interest).

          The device 50 includes a plastics casing, denoted
generally at 51, of rectangular cross-section, which is
20   open at the rear. The casing 51 has respective tabs 60
projecting from its opposite ends. Each of the
projecting tabs 60 has a locating pin 61 for engaging in
a corresponding hole in a support member (not shown),
such as a circuit board, by which the device is
25   supported. Because the pins 61 and tabs 60 are of
relatively small area, the area of contact between the
device and the support member is small, affording good
acoustic isolation of the device from the support member.
This is desirable to prevent the occurrence of parasitic
30   oscillations.

          Respective ribs 62 extend within the casing 51
through the entire height (perpendicular to the plane of
Fig. 6) thereof.

          The casing 51 is formed at its front face with a
35   narrow rectangular slot 63 through which an elongate
piezo-electric ceramic element 53 protrudes. The element
53 is 20.9 mm in length (ℓ), 1 mm in height and 1.5 mm in

thickness. The thickness 1.5 mm of the element 53 (when
the height is 1 mm) provides a structure with a resonant
frequency of approximately 1 MHz since the wavelength of
acoustic waves of this frequency (1 MHz) in the ceramic
5   material is approximately 3 mm. The length of the
element may be varied, but is chosen in dependence upon
the desired extent of the area in which the presence of
an object is to be detected.

     The element 53 is preferably formed from a
10   commercially available lead zirconate titanate ceramic
material, of a "hard" (class 4) or "soft" (class 5) type.
An example of a suitable lead zirconate titanate ceramic
material is manufactured by Vernitron Division of Morgan
Matroc under the proprietary code PZT5H. This material
15   has a high operating efficiency at relatively high
ultrasonic frequencies. The piezo-electric ceramic
element 53 has a natural quality factor Q_{piezo} of about
60, and an acoustic impedance of 3×10^7 Rayls.

     Respective front and rear electrodes 70 and 71 are
20   formed on the front (working) and rear faces of the
ceramic element 53. The front electrode 70, which
extends along the entire length of the front face, has an
end portion 72 which is wrapped around one end of the
element 53 so as to provide a connection point on the
25   rear face of the element. The rear electrode 71 does not
extend along the entire length of the rear face of the
element, but rather extends for a length of some 14 mm
between the two ribs 62. Respective connection wires 55
are connected at their inner ends to the electrodes 70
30   and 71.

     The rear interior portion of the casing 51 is filled
with a backing layer 52 of synthetic resin, such as an
epoxy resin. Polyurethane or other synthetic resins can
alternatively be used. A suitable epoxy resin is known
35   under the proprietary name "Devcon five-minute". The
resin 52 surrounds the rear portion of the piezo-electric
ceramic element 53. The resin 52 has a relatively low Q

value, and is closely coupled to surface areas of the element 53 so as to be capable of dissipating energy due to "ringing" in the piezo-electric element 53.

A rubber matching layer 54 extends over the front electrode 70. The thickness of the layer 54 is chosen to be equal to one quarter of the wavelength of ultrasonic waves passing through that layer. Thus, since for acoustic waves at a frequency of 1 MHz the wavelength of the waves passing through the silicone rubber layer 54 will be approximately 1 mm, the thickness of the layer 54 is preferably about 0.25 mm.

A suitable material for forming the matching layer 54 is low density silicone rubber manufactured by Dow Corning under the proprietary code 170. The density of the rubber in this embodiment is 1.38 $\times 10^3$ kgm^{-3}.

In use of the device of Figs. 6 and 7, the device is located on its support member at a distance of between 27.5 and 42.5 mm from the thread whose presence to be monitored. During a transmission mode of the device, a burst of thirty half-cycle pulses at a frequency of 1 MHz and an amplitude of 38 V is applied to the piezo-electric ceramic element 53 via the front and rear electrodes 70 and 71. Vibrations of the element 53 are then allowed to die away before, during a subsequent reception mode, ultrasonic waves scattered back from the thread are received by the transducer device, the piezo-electric element 53 being caused to vibrate in dependence upon such received waves and providing an output signal, in accordance with such received waves, between the connection wires 55. When coupled to appropriate signal processing circuitry, a sensitivity, to ultrasonic signals, of 70 μV at 1 MHz can be achieved.

Figs. 8(A) and 8(B) show the element 53 and the electrodes 70 and 71 of the transducer of Figs. 6 and 7 in more detail.

The front electrode 70 extends along the whole length of the working face of the element 53, and is

wrapped round one end of the element 53 so as to leave
the end portion 72 of the electrode 70 extending 1 mm
along the rear face of the element 53.

The rear electrode 71 does not extend along the

5   entire length of the element 53, so that respective
portions 73 and 74, of length 3 mm, of the rear face of
the element 53 are not covered by the electrode 71.

The reason for using such electrode structures will
now be explained with reference to Figs. 9 to 11.

10   Fig. 9 shows a simplified view of a typical
detection arrangement employing a transducer device 80
having an elongate piezo-electric element 81 having
respective front and rear electrodes 82 and 83 that
extend fully along the front and rear faces of the

15   element 81. Electrical driving and receiving circuitry
84 is connected with the electrodes 82 and 83.

A thread 85 to be monitored is maintained under
tension a small distance d from the transducer device 80,
the device being disposed such that its longitudinal axis
extends perpendicularly to the axis of the thread 85.

20   The spacing d of the thread 85 from the transducer device
80 is such that the thread occupies a target position in
the near field of the device, which near field extends
from the device for a distance $\ell^2/4\lambda$, where ℓ is the

25   length of the element and λ is the wavelength in air of
emitted acoustic waves.

In use of the transducer device 80 the piezo-
electric element 81 serves both as a transmitter and
receiver of ultrasonic signals. Accordingly, in a first

30   operating mode electrical driving signals at a frequency
substantially equal to the resonant frequency of the
piezo-electric element 81 are applied to the electrodes
82 and 83 by the electrical driver and receiver circuitry
84. Such pulse signals cause the element 81 to expand

35   and contract in the forward/rearward direction so that
the front (working) face of the element 81 having the
electrode 82 is displaced in accordance with the

electrical pulse signals. Accordingly, acoustic waves
are emitted from the front face of the device in the
direction of the thread 85.

5   Subsequently, in a second operating mode the
electrical driver and receiver circuitry 84 becomes
operable to receive electrical signals produced by the
piezo-electric element 81 in accordance with the
impingement thereon of acoustic waves scattered back by
the thread 85 in the direction of the device 80. The
10   circuitry 84 analyses the received signals to determine
whether they are consistent with the presence of the
thread in the target region.

        As mentioned hereinbefore, in practical thread
detector arrangements it is not generally possible to
15   ensure that the position of the thread does not vary.
Thus, the position of the thread 85 in Fig. 9 may vary
from time to time in the forward/rearward direction of
the device 80, and in directions parallel to the
longitudinal axis of the device 80 (along a target line
20   shown at XX in Fig. 9).

        In the case of the latter variation (along line XX)
it is found in practice that the resultant amplitude of
ultrasonic waves arriving at different positions along
the line XX is not uniform, but exhibits a variable
25   characteristic as shown schematically in Fig. 10. The
maximum amplitude of ultrasonic signals is produced at a
position A directly opposite the longitudinal midpoint of
the device 80. However, as shown in Fig. 10, the
resultant amplitude diminishes rapidly as the distance
30   from the midpoint increases, such that at positions
("dead spots") denoted B and C respectively the resultant
amplitude of the ultrasonic waves from the device 80 is
much reduced as compared to the amplitude at the point A.
As the distance from the position A increases further,
35   the amplitude rises again before falling to further
minima at positions denoted D and E respectively.

        When the thread 85 is located at the central

position A the resultant amplitude of the transmitted
acoustic waves reaching the thread 85 is at its highest.
Accordingly, a relatively strong reflected signal will be
produced, which reflected signal will in turn give rise

5   to a significant electrical signal for detection by the
circuitry 84. However, as is clear from Fig. 10, since
the resultant amplitude of the transmitted ultrasonic
signals decreases rapidly as the thread is moved away
from the central position A the detected electrical

10 signal also decreases significantly. Eventually, near
positions B and C, the detected signal may become
indistinguishable from background noise.

Thus, the useful range of positions along the line
XX in which a thread can be reliably detected using the

15 Fig. 9 device is relatively small, perhaps only 10% of
the length ℓ of the transducer. The fact that the
amplitude is sufficient between positions B and D, and
between positions C and E, to permit detection of the
thread is not of much practical value if it is not

20 possible to detect the thread near to positions B and C.

The amplitude variation shown in Fig. 10 arises from
diffraction and interference of the acoustic waves
emitted from the transducer. In the Fig. 9 transducer
device, each point on the front face of the device 80

25 acts as a point source of wavelets, the wavefront from
each such point source being spherical. The wavelets
emitted from the point sources have in principle the same
frequency and amplitude of vibration and their vibrations
are always in phase with one another. These sources are

30 therefore "coherent" sources. Their combined effect at a
given point is obtained by adding algebraically the
displacements at the point concerned due to the sources
individually; this is known as the Principle of
Superposition.

35 At a position a very large distance from the
individual sources, the distance from each individual
source on the transducer front face to the position

concerned is substantially the same (that distance being
very large compared to the dimensions of the transducer
itself), so that the phase of all the wavelets reaching
that position from the individual sources is also

5   substantially the same. At such a remote position,
therefore, the transducer may be regarded as a single
point source.

However, at a position near to the transducer the
respective phases of the wavelets from the individual

10   sources reaching the position concerned vary from one
another considerably according to the respective
distances of the sources from that position.
Accordingly, the wavelets interfere with one another
constructively at certain positions (position A, D and E)

15   and destructively at other positions (for example
positions B and C in Figure 9), giving rise to the
amplitude profile shown in Fig. 10.

In the Fig. 9 arrangement, the thread 85 must be
located relatively close to the transducer for reasons of

20   space and because the attenuation of ultrasonic signals
at the high frequencies involved is relatively high.
Thus, the transducer cannot be spaced from the thread by
a distance sufficient to ensure that the transducer
functions as a point source of ultrasonic waves.

25   To mitigate this problem, as seen in Figs. 8(A) and
8(B) the rear electrode 71 of the device of Figs. 6 and 7
does not extend over the portions 73 and 74, with the
result that the amplitude of vibration produced by the
end regions of the element 53 is less than that produced

30   in the remaining (central) region of that element. Thus,
the amplitude profile of the device 50 of Figs. 6 and 7
is significantly different from that of the device 80 of
Fig. 9. In particular, as shown in Fig. 11, the
variation in amplitude is considerably reduced so that

35   the minima are no longer so pronounced. Thus, the
amplitude at the first pair of minima to either side of
the central position A' (at positions B' and C') is

significantly greater than the amplitude at the
corresponding positions B and C in the Fig. 10 profile.
Accordingly, "dead spots" do not occur at the portions B'
and C', because the amplitude at these positions is
5   sufficiently great for reliable detection of returned
waves.

Thus, because of the particular electrode structures
shown in Figs. 8(A) and 8(B), the effects of the applied
electrical driving signals differ at different locations
10   along the front (working) face of the device 50 so as to
counteract destructive interference effects that would
otherwise occur at some points along the target line XX,
thereby providing a useful range of positions, in which a
thread can be reliably detected, that extends over
15   approximately 70% of the length ℓ of the transducer
device.

Figs. 12 to 15 show respective side elevational
views of alternative preferred elements and their
associated electrodes for use in devices embodying the
20   invention.

In Fig. 12 a piezo-electric element 90 is provided
on one face thereof with a single continuous electrode
91, the electrode structure 92 on the opposite face of
the element 90 being composed of five separate mutually-
25   spaced portions 92a to 92e. Each of the portions 92a to
92e, however, receives the same electrical signal. As
compared to the arrangement shown in Figs. 8(A) and 8(B),
it is apparent that the arrangement of Fig. 12 is more
complex, but can provide more sophisticated control of
30   the amplitude profile.

A piezo-electric element 100 of Fig. 13(A) also has
a continuous electrode 101 along one face thereof but has
a plurality of individually-driven separate electrode
portions 102a to 102k on its opposite face. The
35   respective drive voltages to the portions 102a to 102k
differ from one another as shown in Fig. 13(B). The
individual electrode portions 102a to 102k may be formed

by depositing a single continuous electrode on the face
of the element concerned and then scribing that
continuous electrode. The electrode 101 may also be
provided as a plurality of individual electrode portions.

5   In Fig. 14, a piezo-electric element 110 again has a
single continuous electrode 111 extending along the full
length of one face, but at the opposite face a dielectric
layer 112 is interposed between a second electrode 113
and the element 110. The thickness of the layer 112

10   increases progressively in both longitudinal directions
away from the longitudinal mid-point of the element 110.

         In Fig. 15(A) a bare piezo-electric element 120 is
prepared by temporarily contacting opposite sides thereof
with respective first and second poling electrodes 121

15   and 122. The first poling electrode 121 extends along
the full length of the element 120, but the second poling
electrode 122 only extends over a central longitudinal
region thereof. The poling electrodes 121 and 122 may be
conductive rubber pads, for example. A high d.c. voltage

20   of for example 2000-3000V is applied between the
electrodes 121 and 122 for a short period, of several
minutes duration for example, the temperature of the
element 70 being elevated during this period to perhaps
90°C. Thereafter, the poling electrodes 121 and 122 are

25   removed and then, as shown in Fig. 15(B), full continuous
electrodes 123 and 124 are mounted on opposite faces of
the element 120. In use of the element 120 of Fig.
15(B), the poorer poling of the element 120 at its ends
gives rise to the preferred amplitude profile.

30   It will be appreciated that the electrode structures
shown in Figs. 8(A) and 8(B), and in Figs. 12 to 15, can
also be applied effectively to other forms of electro-
acoustic elements, such as electrostatic elements, to
enable the amplitude profiles of those other elements to

35   be similarly modified.

         For reasons explained below with reference to
Figures 16 to 19, the transducer has a preferred height

of 1.0 mm, this being the narrower dimension of the
elongate working face of the piezo-electric element.

It is to be noted that the thread is located in the
far field region of the vertical field of view of the
5   transducer. This region starts at a distance from the
transducer defined by $\frac{D^2}{4\lambda}$ where D

is the height of the transducer.

For example for a transducer of height D generating
10 sound with wavelength λ, the sound wave generated will
correspond to the diffraction pattern generated by a
plane wave striking a slit of height D. It will thus
consist of a primary lobe with half-angle θ given by:

15                      $$\text{Sin } \theta = \frac{\lambda}{D} \qquad \text{Equation A}$$

and a number of secondary lobes as seen in Fig. 16.

The sound wave will travel to the thread 3 which is
20 disposed at an angle α to the vertical, and be reflected
back towards the transducer. As can be seen from Figure
16, the amplitude of the primary lobe is far greater than
that of the secondary lobes. Thus if any appreciable
signal is to be received, sound from the primary lobe
25 must be reflected back onto the transducer. As can be
seen from Figure 17 the upper section of the beam,
travelling with a wave-front at an angle θ to the
vertical will strike the thread 3, which is at an angle α
to the vertical, and be reflected so that the beam is
30 travelling at an angle of $(2\alpha-\theta)$ to the vertical. This
part of the beam will reach the transducer at a height
$2d(\alpha-\theta)$ below the transducer. For the beam to hit the
transducer, this distance must be less than half the
transducer height. i.e.

35                      $$2d(\alpha-\theta) < \frac{D}{2}$$

As mentioned, d may be as great as 42.5 mm and α as
great as 10°. Using the operating frequency of the

device of Figs. 6 and 7, i.e. 1 MHz then, substituting
for θ using Equation A:

$$\frac{D}{2} + \frac{28}{D} > 15$$

5

This means that

$$D < 2.0 \text{ mm}$$
or $$D > 28 \text{ mm}$$

10

When D is greater than 2.0 mm, for example 5 mm, as
shown in Figure 18, a narrow sound cone is generated from
the transducer which misses the transducer after
reflection by a thread 3 angled at 10°.

15   A further constraint is that, to avoid destructive
interference, the phase of the returning signal should
vary by significantly less than one cycle across the
surface of the transducer. That is that:

$$D\,\alpha < \lambda$$

20   or substituting for α and λ

$$D < 1.9 \text{ mm}$$

Thus, by choosing D to be less than 1.9 mm, it can be
ensured that, when the filament is at its greatest angle,
10°, the reflected beam strikes the transducer and the
25   components across the surface do not interfere
destructively. It is important however, that the beam is
not too divergent (as shown in Fig. 19) as this will
reduce the received signal amplitude. As can be seen,
the wide cone created by the transducer (which is 0.5 mm
30   high) allows detection of threads which are disposed at
angles from the vertical, but only a small fraction of
the reflection is received by the transducer. If the
beam has a half angle of θ than the fraction of the
wavefront falling on the transducer is:

35      $$\frac{D}{4l\theta} = \frac{D^2}{4l\lambda}$$

As the amplitude is also proportional to D, the size
of the aperture, the result is that the pressure
40   amplitude of the received signal goes as:

$$\underline{D}^3$$

41λ

For this reason the transducer height, D, must be chosen
to be the largest value consistent with θ>α.

5   A further constraint on D comes from considerations
concerning the piezo-ceramic resonant modes. It is well
established that a piezo will operate efficiently when
the height, D, is approximated one half its thickness, t,
and inefficiently when the height is approximately equal

10   to its thickness. For operation at 1MHz a thickness of
1.5 - 1.8 mm is required (depending on the height) and
thus for efficient operation it is wise to choose a
height between 1.0 and 0.75 mm.

        It has therefore been found that a height of 1.0 mm

15   gives efficient transduction while generating sound with
a suitable cone angle.

        It can therefore be seen that using a combined
theoretical and empirical approach it has been
established that a transducer whose height is 1 mm allows

20   sound to be transmitted and received over a suitable
range of thread angles. If the transducer is too high
then two effects reduce the angular performance,
geometric shadowing and interference. With geometric
shadowing a collimated beam is reflected specularly from

25   an angled thread and so misses the transducer.

        If the phase of the reflected beam varies by one
cycle over the height of transducer then it will
interfere destructively. These two effects combine to
reduce the height.

30   However if the transducer is made too narrow then
the transmitted acoustic energy will be reduced and
reduce signal strength unnecessarily.

CLAIMS:

1.   An ultrasonic electro-acoustic transducer (50)
comprising an electro-acoustic element (53) having an
elongate working face, bearing a first electrode
5   structure (70), and a second face spaced from the said
working face and bearing a second electrode structure
(71);

there being electrical driving circuitry
connected to the first and second electrode structures
10   for applying electrical driving signals therebetween to
cause the element to vibrate so that ultrasonic acoustic
waves are propagated, into a medium coupled to the said
elongate working face, in a direction away from that
working face;

15   and the said electro-acoustic element,
electrode structures and driving circuitry being such
that the effects of the said electrical driving signals
differ at different locations along the said working face
so as to counteract destructive interference effects that
20   would otherwise occur at points, in the said medium,
along a target line parallel to the said longitudinal
axis and spaced at a predetermined distance in the said
direction from the said working face.

2.   A transducer as claimed in claim 1, wherein the
25   said working face and the said second face are of
substantially the same dimensions.

3.   A transducer as claimed in any preceding claim,
wherein the said first electrode structure comprises a
first electrically-conductive strip (70) extending over
30   the full length of the said elongate working face, and
the said second electrode structure comprises a second
electrically-conductive strip (71) extending over only a
central portion of the said second face.

4.   A transducer as claimed in claim 3, wherein the
35   respective widths of the said first and second
electrically-conductive strips (70, 71) are substantially
equal to the widths of the said elongate working face and

the said second face respectively.

　　　5.　　A transducer as claimed in claim 3 or 4, wherein the length of the said second electrically-conductive strip (71) is substantially two-thirds of the

5　length of the said second face.

　　　6.　　A transducer as claimed in any one of claims 3 to 5, wherein the respective widths of the said first and second electrically-conductive strips (70, 71) are substantially the same.

10　　　7.　　A transducer as claimed in claim 1 or 2, wherein the said first electrode structure comprises a first electrically-conductive strip (91) extending over the full length of the said elongate working face and the said second electrode structure comprises a plurality of

15　separate further electrically-conductive strips (92a, 92b,..92e) extending over different respective longitudinal portions of the said second face.

　　　8.　　A transducer as claimed in claim 7, wherein the said electrical driving circuitry is operable to apply

20　substantially the same electrical driving signals to each of the said further electrically-conductive strips (92a-92e).

　　　9.　　A transducer as claimed in claim 7, wherein each of the said further electrically-conductive strips

25　(102a-102k) is of substantially the same length, and the said electrical driving circuitry is operable to apply different respective electrical signals to the said further electrically-conductive strips (102a-102k) such that the electrical potential differs at different

30　locations along the said second face when the transducer is in use.

　　　10.　A transducer as claimed in claim 9, wherein the said different respective electrical driving signals are such that the respective electrical potentials between

35　the said further electrically-conductive strips (102a-102k) and the said first electrically-conductive strip (101) decrease successively in the outward directions

from a central location along the longitudinal axis of
the said second face towards the ends of that face.

11.   A transducer as claimed in claim 1 or 2,
wherein the said first electrode structure comprises a
5   first electrically-conductive strip (111) extending over
the full length of the said elongate working face, and
the said second electrode structure comprises a
dielectric strip (112) formed on the said second face and
a second electrically-conductive strip (113) formed on
10   the said dielectric strip, the thickness of the said
dielectric strip (113) increasing progressively in the
outward directions from a central location along the
longitudinal axis of the said second face towards the
ends of that face.

15   12.   A transducer as claimed in claim 1 or 2,
wherein the said first and second electrode structures
comprise respective electrically-conductive strips (123,
124) extending along the full length of the said elongate
working face and the said second face respectively, the
20   said electro-acoustic element (120) having been
selectively poled at different locations along the
longitudinal axis of the element by temporarily
contacting the said elongate working face and the said
second face of the element (120) with respective poling
25   electrodes (121, 122) having a predetermined potential
difference therebetween.

13.   A transducer as claimed in claim 12, wherein _
the said poling electrodes (121, 122) were electrically-
conductive rubber pads.

30   14.   A transducer device as claimed in claim 12 or
13, wherein the temperature of the said element (120) was
elevated during such poling.

15.   A transducer as claimed in any one of claims 12
to 14, wherein the ends of the element were poled less
35   than a central portion thereof.

16.   A transducer as claimed in any preceding claim,
wherein the said electro-acoustic element (53) is a

piezo-electric ceramic element.

17.   A transducer as claimed in any preceding claim, wherein the frequency of the said acoustic waves is in the range from 0.8 to 1.2 MHz.
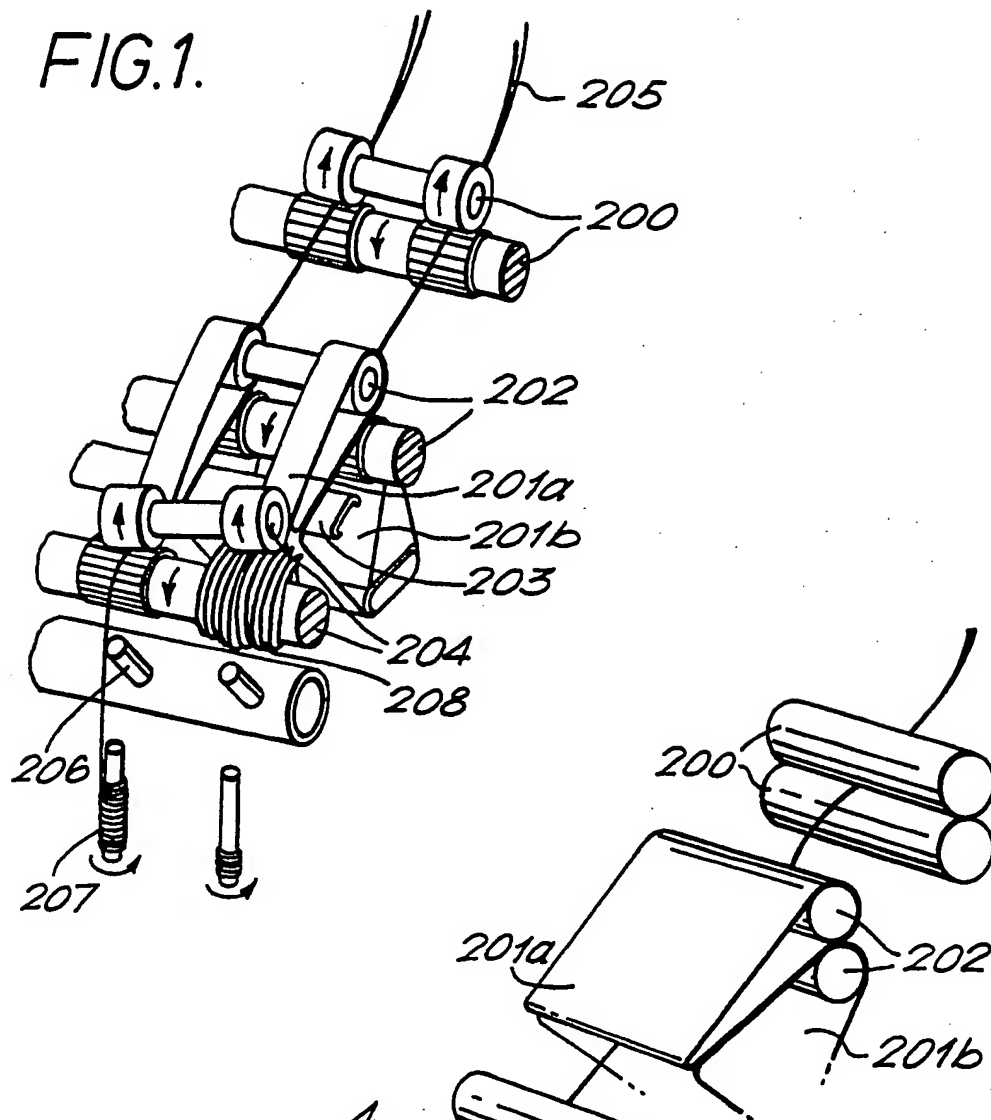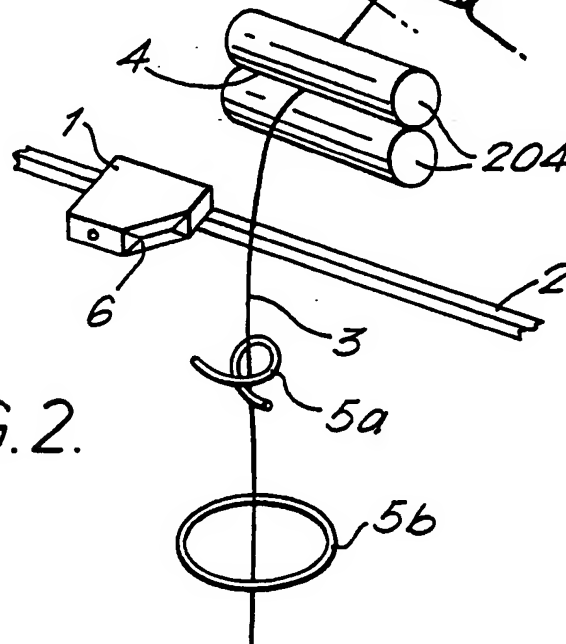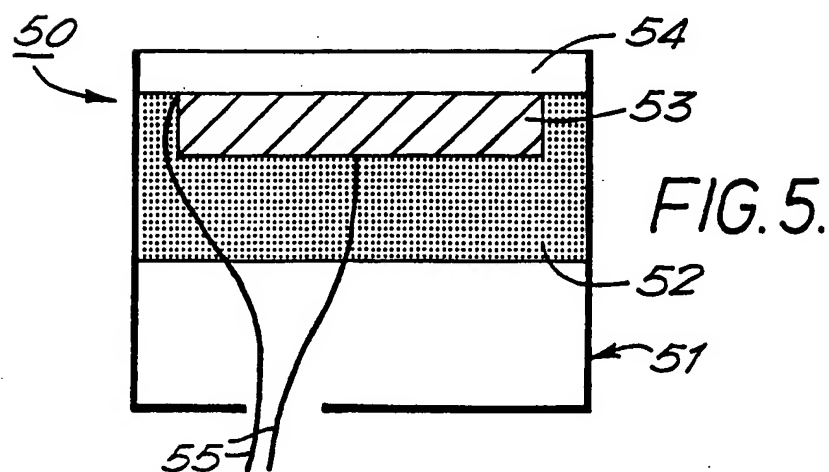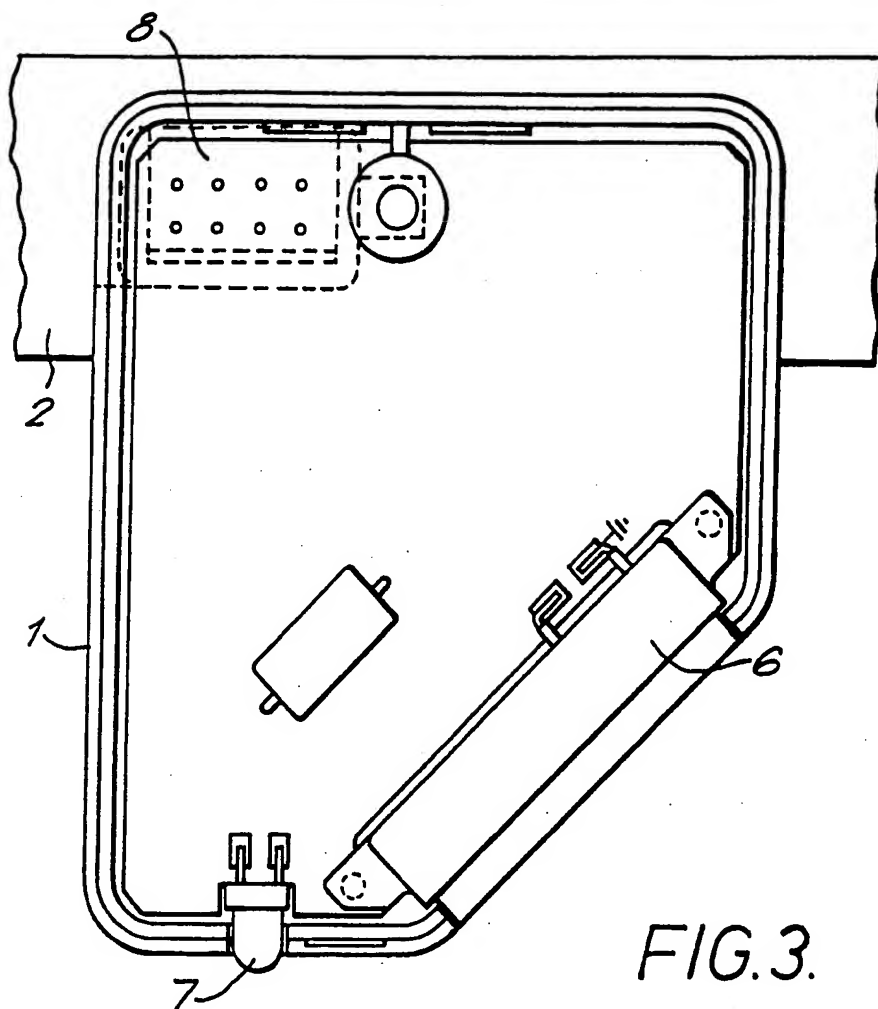
FIG.1.

205

200

202

201a

201b

203

204

208

206

207

200

201a

202

201b

4

204

1

6

2

3

5a

FIG.2.

5b

FIG.3.

FIG.5.

FIG.4.

FIG.6.

FIG.7.

FIG.8(A)

FIG.8(B)

FIG.9.


FIG.10.

FIG.11.

6/9

FIG.12.

92a 92b 92c 92d 92e

90

91

FIG.13(A)

102a   102k

101   100

FIG.13(B)

DRIVE
VOLTAGE
AMPLITUDE

a - - - -   - - - - k POSITION

FIG.14.

113   112

110

111

7/9

V+ 122
120

FIG.15(A)

V- 121

124 120

123

FIG.15(B)

FIG.16.

00

3

900
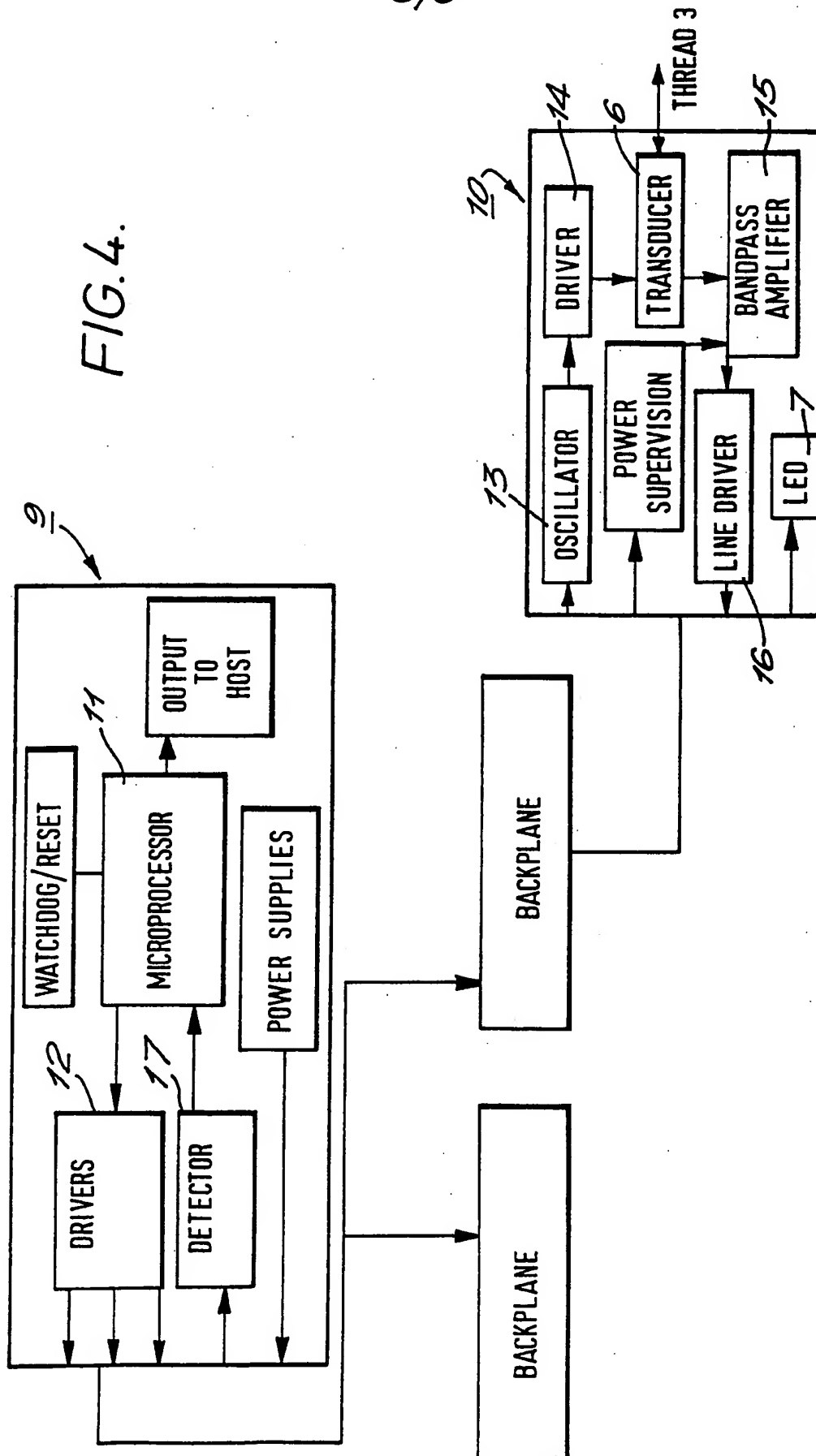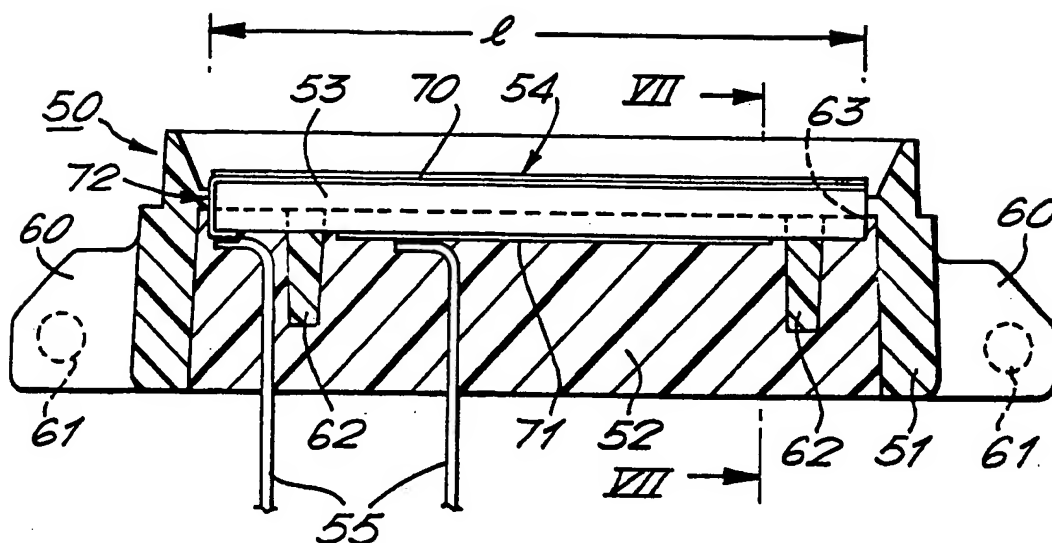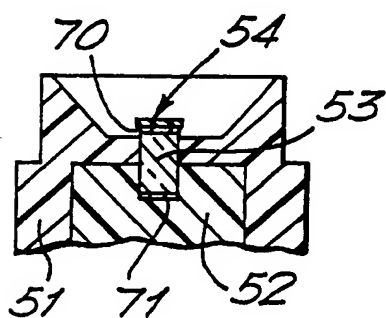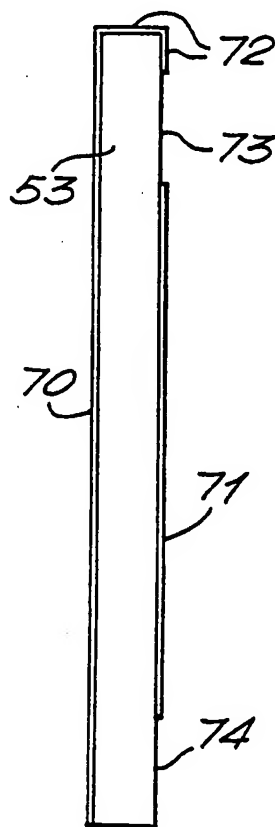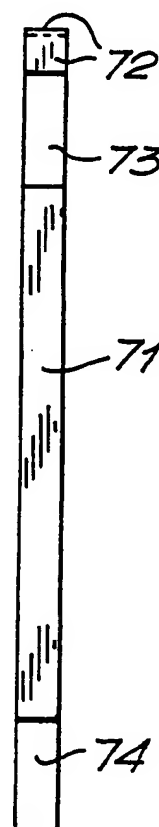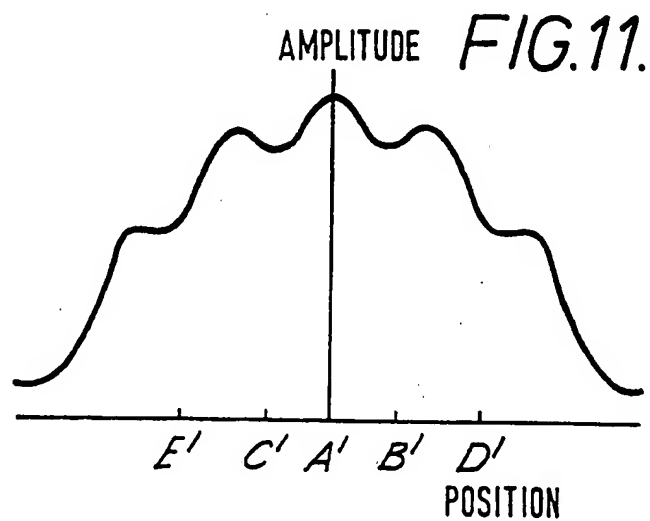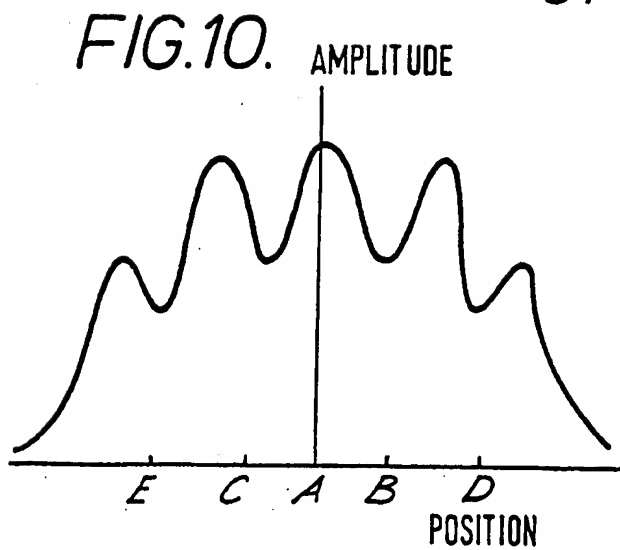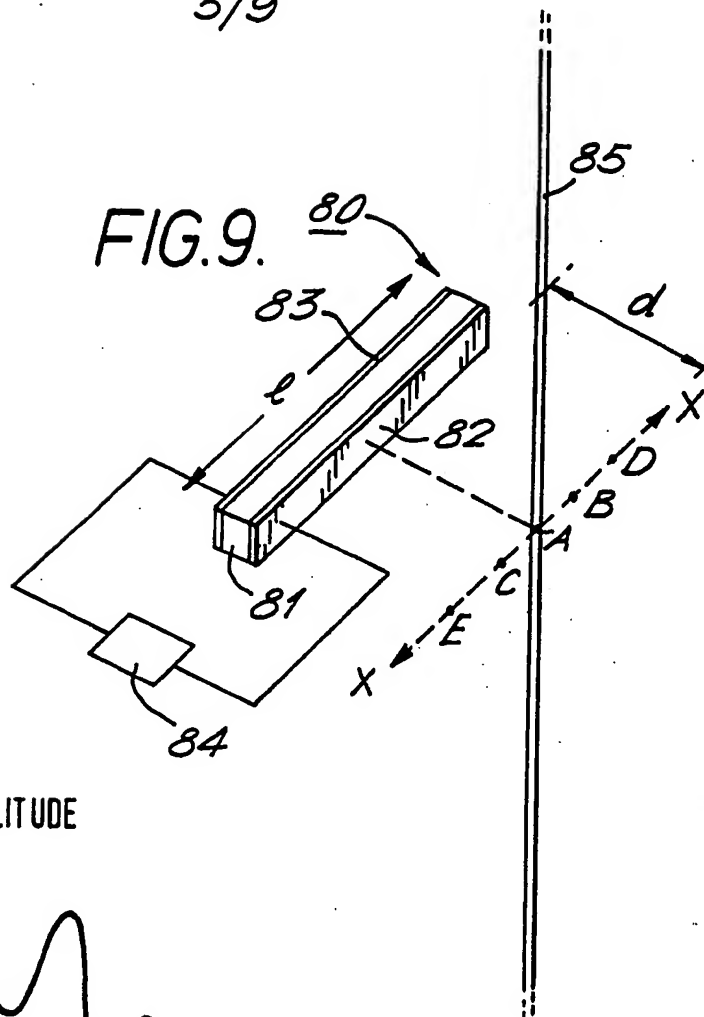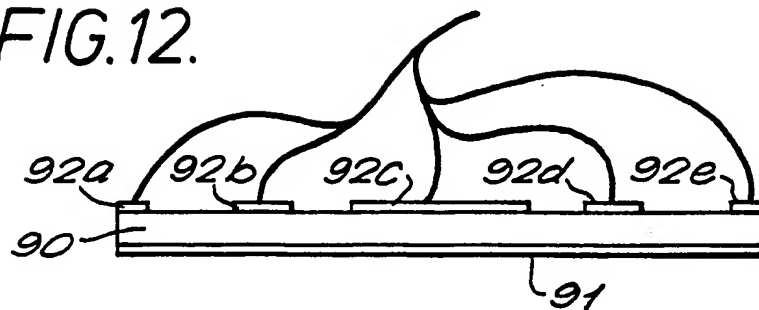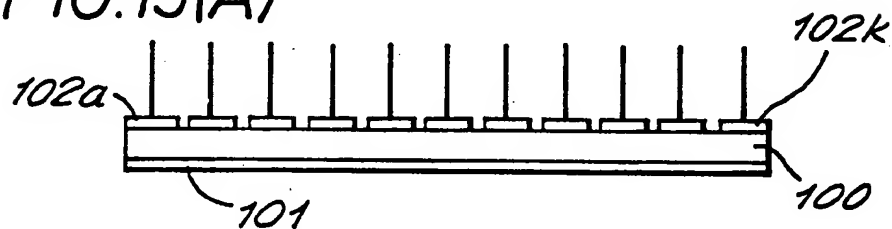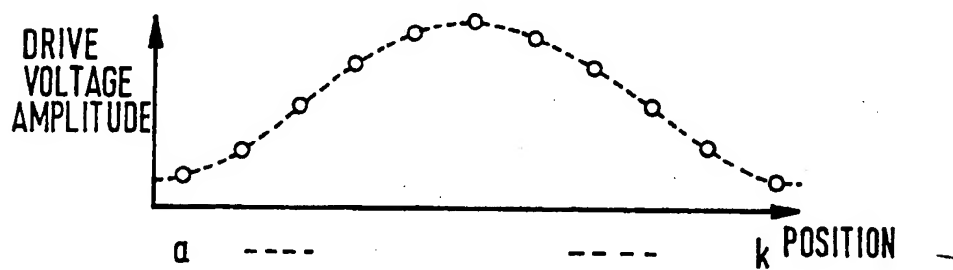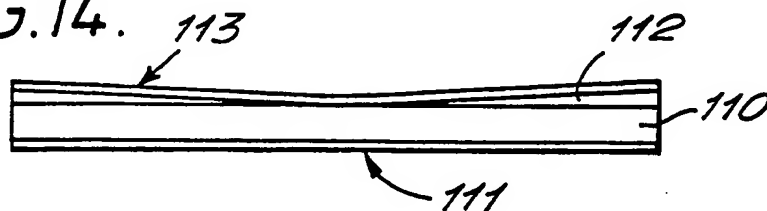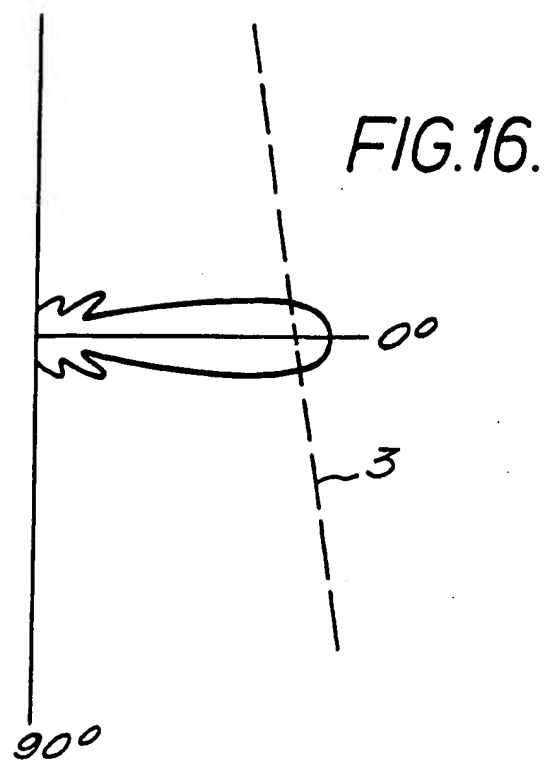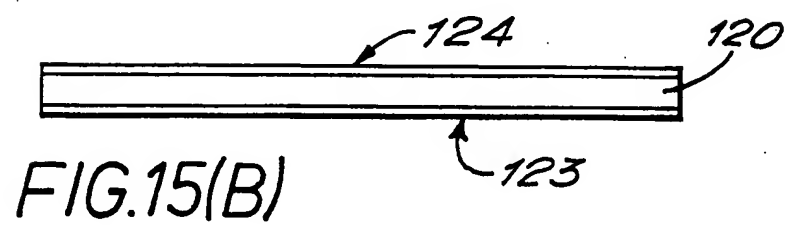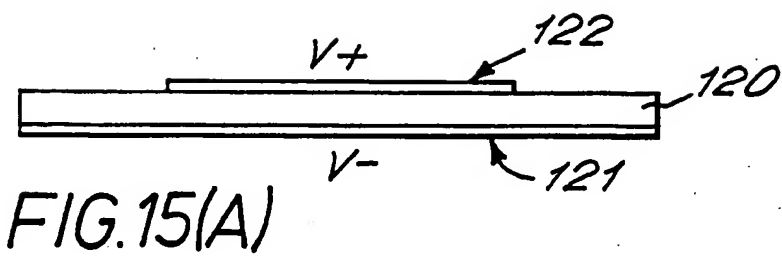
FIG.17.
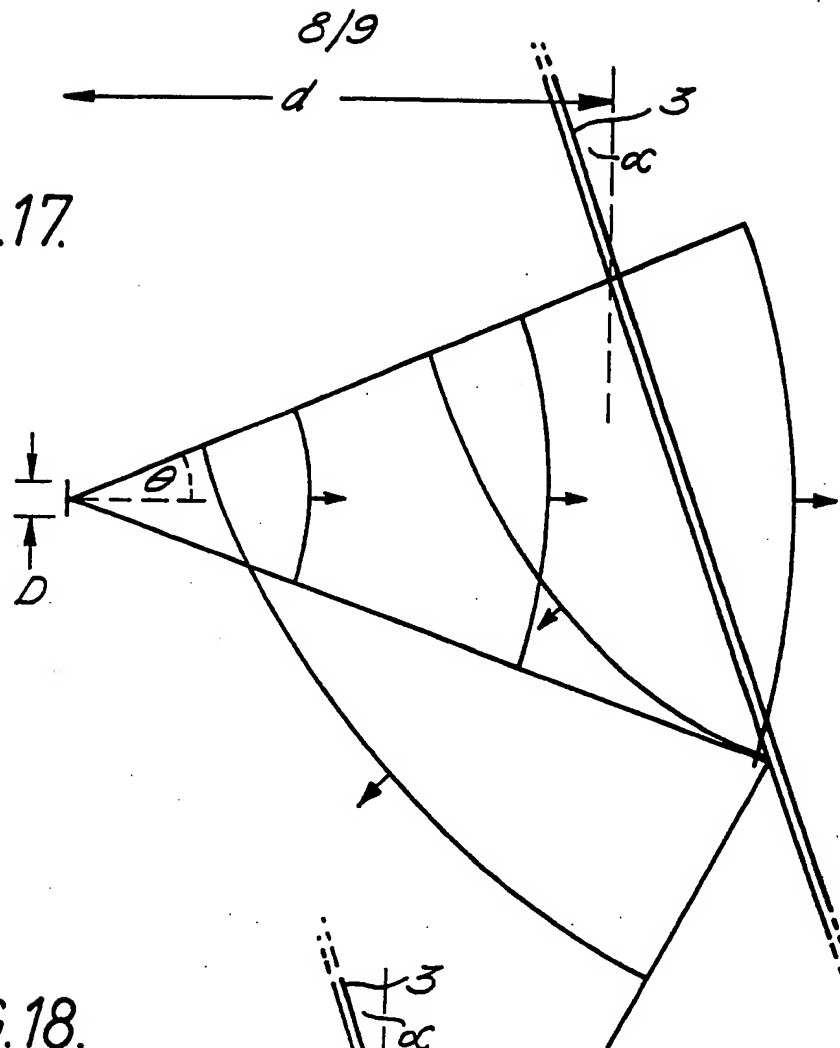
FIG.18.
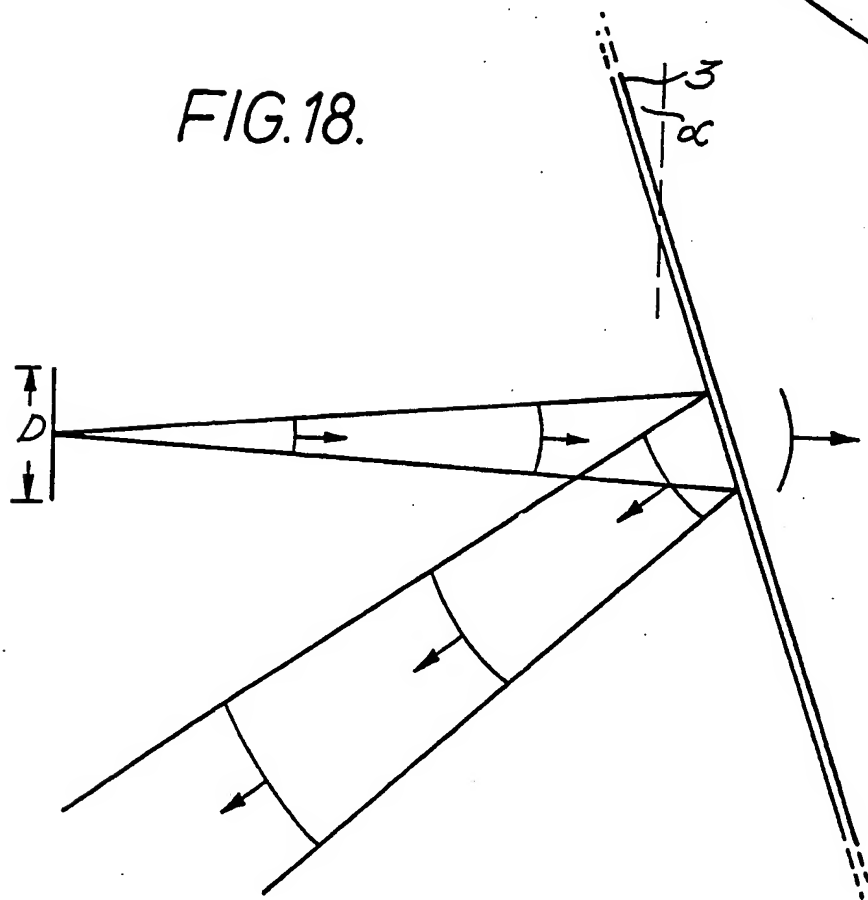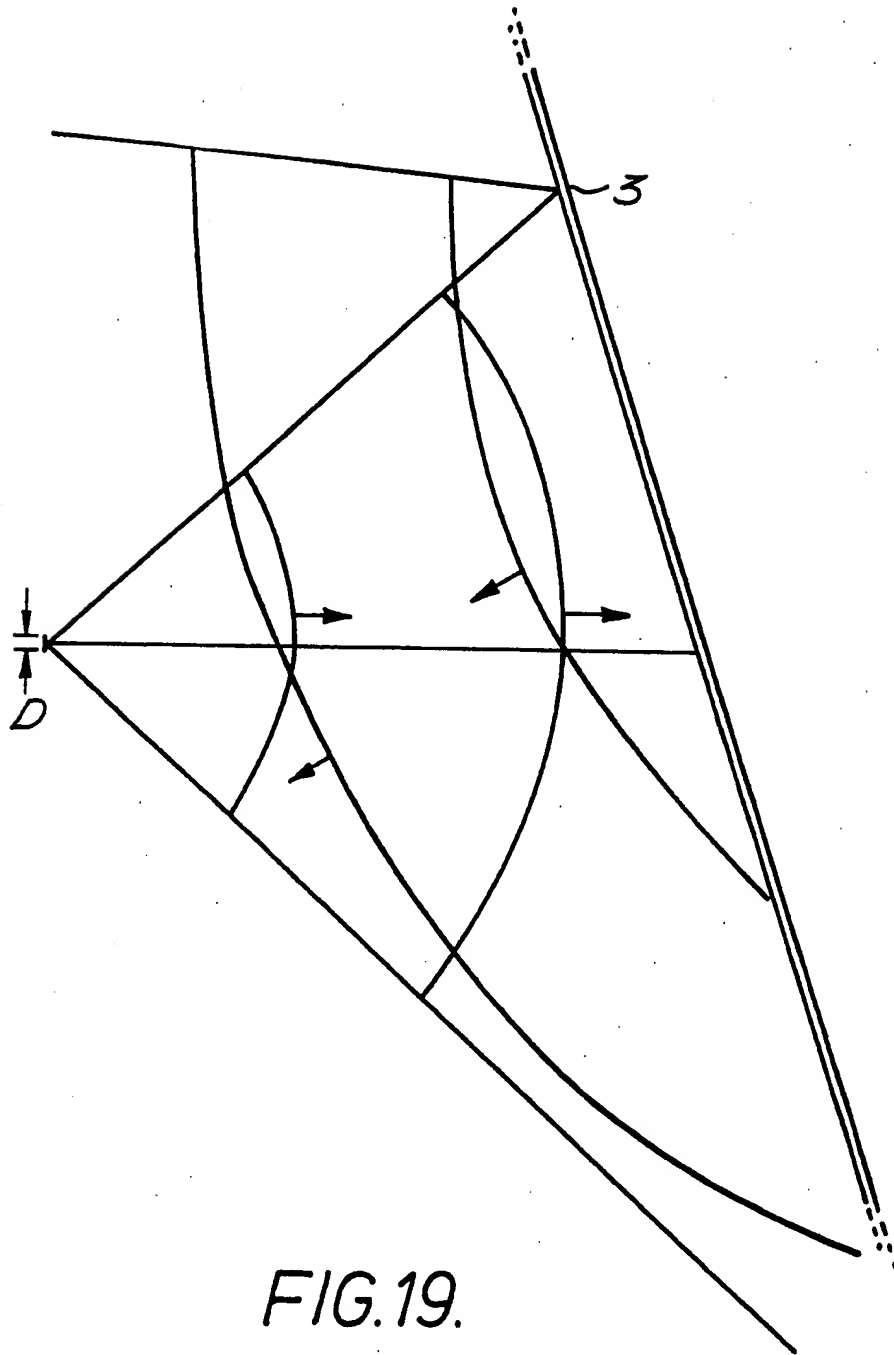
FIG.19.

INTERNATIONAL SEARCH REPORT

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)⁶

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl.5   B 06 B   1/06

II. FIELDS SEARCHED

Minimum Documentation Searched⁷

Classification System	Classification Symbols
Int.Cl.5	B 06 B

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched⁸

III. DOCUMENTS CONSIDERED TO BE RELEVANT⁹

Category⁶	Citation of Document,¹¹ with indication, where appropriate, of the relevant passages¹²	Relevant to Claim No.¹³
A	US,A,3025419 (METTLER) 13 March 1962, see figures 2-4	1-6
A	US,A,4446396 (CLAUS et al.) 01 May 1984, see figures 2,3	9-10
A	GB,A,2190818 (AKTIESELSKABET BRUEL + KJAER) 25 November 1987, see abstract; figure 5	11
A	US,A,3374367 (COWAN) 19 March 1968, see claim 1	12

⁶ Special categories of cited documents :¹⁰

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
22-10-1991	1 1. 11. 91

International Searching Authority	Signature of Authorized Officer
EUROPEAN PATENT OFFICE	Danielle van der Haas

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 06/11/91
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US-A- 3025419		US-E-	RE25657	
US-A- 4446396	01-05-84	None		
GB-A- 2190818	25-11-87	AT-B-	388479	26-06-89
		DE-A-	3713798	12-11-87
		FR-A-	2598581	13-11-87
		JP-A-	62290300	17-12-87
		US-A-	4910838	27-03-90
US-A- 3374367		None		

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For more details about this annex : see Official Journal of the European Patent Office. No. 12/82